LOW COST USING ULTRA-THIN BIFACIAL CELLS

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ABSTRACT: This paper presents the global results of the BiThink project. This is a project financed by DG-TREN. The BiThink objective is to develop and demonstrate an industrial technology able to exert direct influence on the cost of photovoltaic systems. BiThink focuses on three key aspects: the use of bifacial cells and albedo modules as a simple way to increase the amount of energy collected, the increase in the number of wafers obtained from the slicing of silicon ingots and the use of a simple and at last an efficient manufacturing process, able to combine high mechanical yields with reasonable cell efficiency. BiThink shows impressive figures in terms of the consumption of silicon: 5.9 grams per Watt peak using conservative yield values. Another important result is the large amount of new technology developed in the project in the areas of ingot slicing, post-slicing wafer separation, screen printing diffusion, mechanical handling, crack detection, and thin solar cell interconnection.
Keywords: Bifacial, Silicon, Screen Printing

1 INTRODUCTION

Reaching low costs in present and future photovoltaics requires the reduction of expenses in raw materials. Using thinner silicon wafers is the clearest path to reach photovoltaic competitiveness, an idea widely accepted by the PV community.

BiThink is a project funded by the European Commission having transoceanic partners. The main BiThink's objective is to reduce significantly the cost of industrial PV silicon solar cells and modules. To this objective work has been focused on three different points:

- To use bifacial cells and albedo modules as a simple way to have more energy from the same silicon area without the use of optics or concentration
- To increase the number of sliced wafers per linear meter of silicon ingot
- To implement an efficient and simple manufacturing process, able to combine high mechanical yield values with reasonable cell efficiency

BiThink covers the whole chain of manufacturing solar modules, from the slicing of silicon ingots to the lamination of cells and testing of modules.

2 BIFACIAL CELLS AND ALBEDO MODULES

Bifacial solar cells and albedo modules were produced by Isofoton (patent from A. Luque, 1976) since 1982. These modules, with both active surfaces, are able to capture the light reflected by the surrounding areas to the PV system and convert it into electricity. Having a white painted floor or wall close to the PV modules the extra power, the albedo factor, would be over 30% of the conventional front incident light. This albedo factor would grow in cloudy climates or even be as large as 50% if a dihedron (floor plus wall) is used as reflective surfaces [1]. Bifacial cells using a simple BSF structure present a symmetry in the photocurrent produced from rear or front illumination that ranges from 60% (for minority carrier diffusion lengths similar to the base thickness) to 100% for diffusion lengths over two times the base thickness. This is easily achievable on thin CZ n-type substrates. Figure 1 and 2 show the expected bifaciality (obtained from analytical models) regarding the lifetime value of the base minority carriers. In these figures a n-type silicon substrate has been considered. Apart from the requirement of medium to high values of the minority-carrier lifetime, bifaciality can be improved significantly by using thin substrates. Base doping plays also an important role in reaching the highest bifaciality value. Medium to high resistivity substrates, 2 to 4 ohms.cm, are needed for this purpose.

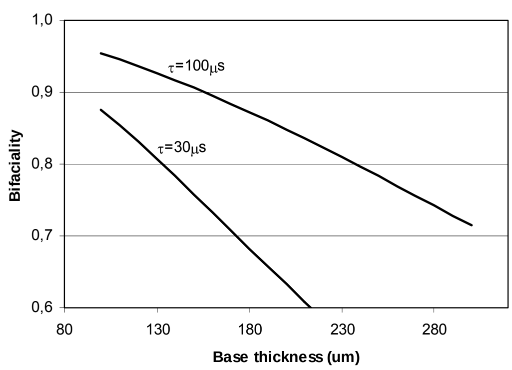

Figure 1: Bifaciality vs. base thickness for n-type silicon substrates and two lifetime values. A base doping of 10^{15} cm^{-3} has been considered and saturation current from the rear emitter of 3.10^{-13} A/cm^2

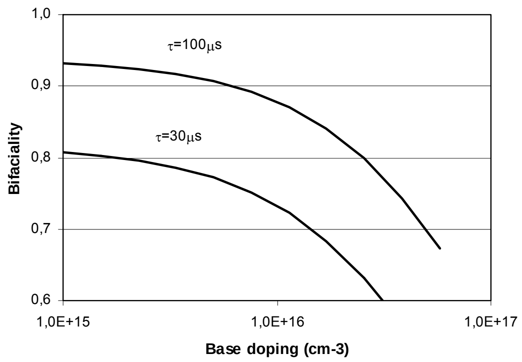

Figure 2: Bifaciality vs. base doping for n-type silicon substrates, base thickness of 130 µm and saturation current from the rear emitter of 3.10^{-13} A/cm^2

3 THIN SLICING OF SILICON INGOTS

Thin slicing of ingots was carried out by HCT Company using the Multi-Wire Slurry Slicing, technique, MWSS. Figure 3 shows the record of cuts in this project, ranging from over 250 µm thick to lower than 100 µm. Wire diameters have been varied from 160 µm to 120 µm and pitch has been varied from 530 µm to 280 µm. It is remarkable that the Total Thickness Variation, TTV, which is a limiting variation in the lower achievable thickness, was independent of the final thickness of the wafer, as can be seen in figure 4.

The target of the project was to go from the industrial value of 1800 wafers per linear meter of silicon ingot (w/m) towards the range of 3500 – 4000 w/m. An intermediate target of 2500 w/m has been reached from the very beginning of the project. The current status is more than 3500 w/m over a 156x156 mm multicrystalline silicon brick. The pitch was 280 µm with a final wafer thickness of 120 µm. The TTV is in average of 31 µm with standard deviation of 3 µm. The standard deviation for the central thickness is only of 2 µm. This result means a gain of 88% over technology at the start of the project. Table I summarizes the progress of slicing technology in the BiThink project. A challenging objective was the singulation of thin sliced wafers with high yield values. A work between HCT and Deker companies reached to the design of a singulation system [2] based on Van Der Waals forces (see Fig. 5).

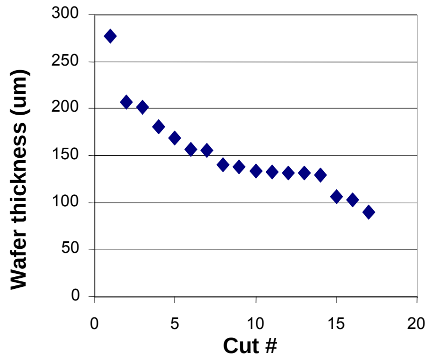

Figure 3: Cut summary

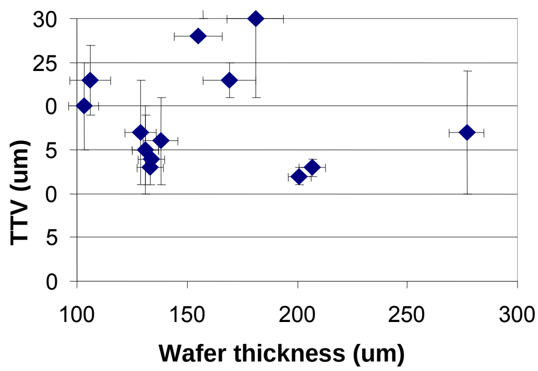

Figure 4: Total Thickness Variation vs. wafer thickness

Figure 5: Prototype for wafer singulation

Table I: Progress of slicing technology in BiThink project

		In production	BiThink 1^{st} milestone	Current technology	Future technology
Wafer thickness	µm	**330**	**200**	**120**	**85-92**
Wire diameter	µm	160	160	120	110-120
Grit size	µm	15	15	10	8-10
Production yield	%	95	95	95	90-85
Kerf loss	µm	198	198	160	144-158
Surface damage (1 side)	µm	23	23	15	13-15
Final wafer thickness	µm	285	155	90	73-76
Pitch average	µm	528	398	280	250-229
Raw material usage:					
wafer / cm		18.0	23.9	33.9	36.0-37.12
m^2 / kg		0.77	1.03	1.45	1.55-1.59

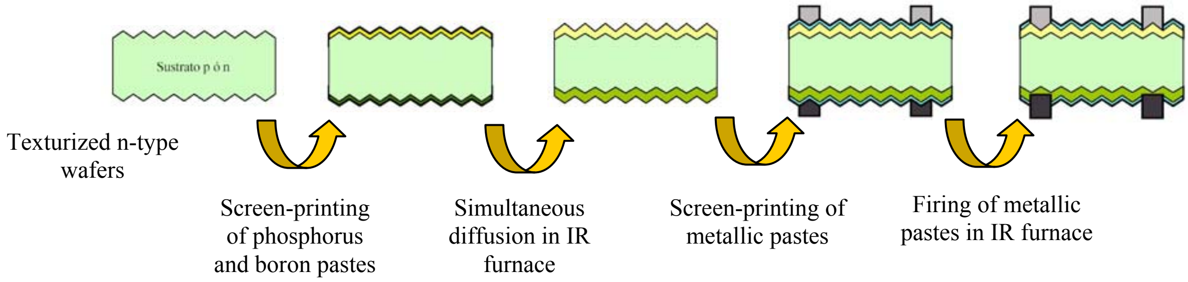

Figure 6: Manufacturing process of BSF bifacial solar cells

4 SOLAR CELL TECHNOLOGY

Bifacial cells are fabricated by a very simple and efficient process. That gives rise to high yield values and to a very robust process. Figure 6 shows the flowchart of cell processing. This process could be used over p or n type Cz or multi-crystalline silicon.

Solar cell processing is based in screen-printing of dopants and electrical contacts. Screen-printing has been selected as base line technology for its low cost and its ability to be used in automated large production lines. The main challenge was to produce a boron emitter without degrading the material properties and having low saturation currents after metallization [3-6]. A junction depth of 0.35 µm for the boron emitter and the addition of extra components and reformulation of the silver-based paste have produced a relevant decrease in the junction recombination current.

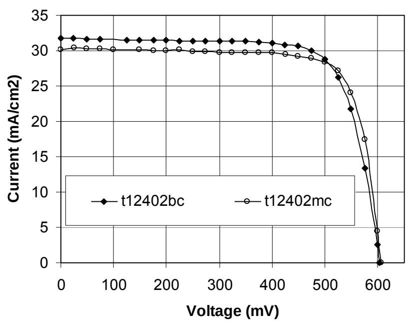

Figure 7: I-V characteristics of 2 pnn^+ solar cells illuminated by the boron face

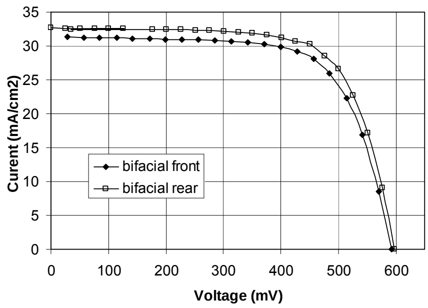

Figure 8: I-V characteristics of a pnn^+ bifacial cell

Table II: Internal parameters of cells from Fig. 7 & 8

n+np+	***t12402bc***	***t12402mc***	***Bifacial front***	***Bifacial rear***
Base thickness (µm)	321	321	120	120
Resistivity (Ω·cm)	0.8	0.8	4	4
η (%)	**14.4**	**14.2**	**12.76**	**13.24**
Voc (mV)	**603.5**	**607**	***592.58***	***598.04***
J_g (mA/cm^2)	**31.7**	**30.2**	**31.2**	**31.80**
FF (%)	**75.2**	**77.7**	**69**	**69.63**
J_{01} (pA/cm^2)	1.76	1.23	*1.56*	*0.2*
J_{02} (nA/cm^2)	20.6	46	114	140
R_s (Ω·cm^2)	0.84	0.32	0.89	0.52
G_{shunt} (Ω^{-1}/cm^2)	$5.94 \cdot 10^{-4}$	$4.12 \cdot 10^{-4}$	$6.0 \cdot 10^{-4}$	$4.7 \cdot 10^{-4}$

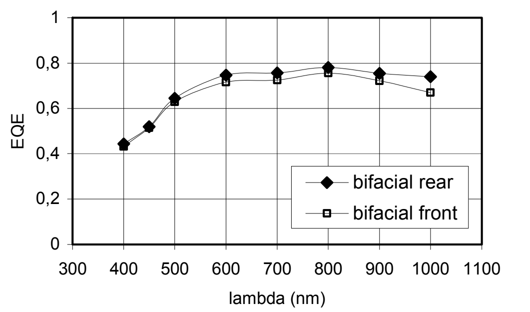

Figure 9: External quantum efficiency of cell in Fig. 8

Figure 7 shows the I-V curves of two cells made on n-type, 0.8 Ω·cm, Cz wafers. A single co-diffusion step at 1000º C, 8 minutes, has been used. Efficiencies over 14% has been obtained but without using any specific antireflective layer. Efficiencies in the range of 15% are expected only by the optimization of their AR properties. For these cells bifaciality is only 18%. Using higher resistivity substrates, 4 Ω·cm, and with lower temperature co-diffusion, 950º C during 35 minutes, bifaciality exceeds 100%, as it can be seen in fig. 8. Lower fill factor of these cells is only due to the dicing process. Technology developed at BiThink project is able to produce 15% cells with 100% bifaciality.

5 YIELD AND MECHANICAL ASPECTS

To maintain a high mechanical yield is a key task to work with ultra-thin silicon wafers. Increasing the mechanical yield will be based on a better knowledge of the mechanical behaviour of solar cells. BiThink is carrying out some work in mechanical modelling, mechanical strength of wafers in different process steps and early detection of mechanical defects. The Resonant Ultrasonic Vibration Technique [7] has been revealed as a powerful technique for the detection of cracks, both in Cz and multi-crystalline wafers. In this technique the ultrasonic resonant frequencies of wafers are analyzed. When a crack appears, both the frequency peak position and the bandwidth are modified (fig. 10) and the sensitivity to this crack is a function of the standard deviations of these parameters [8].

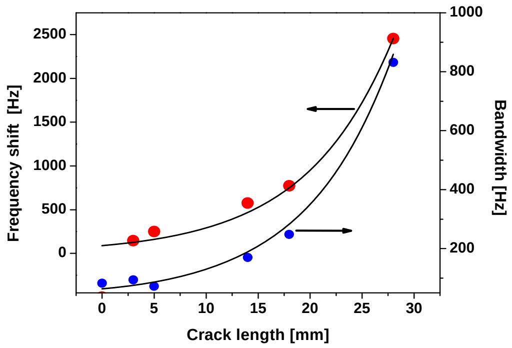

Figure 10: Frecuency shift and badwith broadening as a function of crack lenth

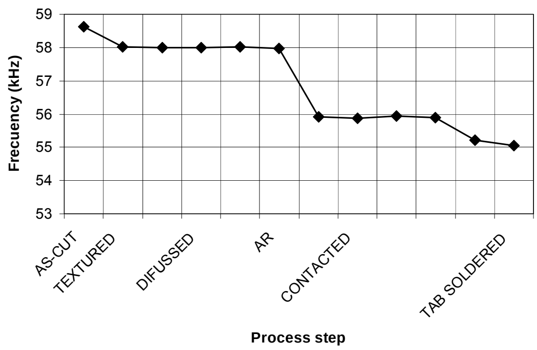

Figure 11: Value of the peak position through the manufacturing step

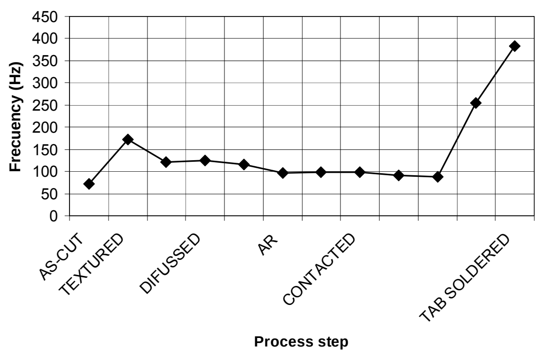

Figure 12: Standard deviation for the peak position through the manufacturing step

6 CONCLUSIONS

Technology developed in the BiThink project is demonstrating impressive numbers in low consumption of silicon: 3500 wafers can be obtained from a meter of silicon ingot with a 95% yield that means 1.45 m^2 of silicon wafers from a kilogram of silicon. Using the current BSF bifacial technology, with an efficiency of 13%, 100% bifaciality and using the lower albedo factor of 30%, gives a consumption of 3.9 grams/Wp without taking account the yield. Using the 95% of yield for the slicing process and 90% for the solar cell production this number is 4.6 g/Wp. The simple optimization of cell technology to 15% of efficiency with bifaciality of 100% gives to values lower than 4 g/Wp.

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REFERENCES

[1] S. L. Romero, “Contribución al estudio de las células solares bifaciales y su empleo en superficies de alto albedo”. Doctoral Thesis, IES-UPM (Spain), 1984.

[2] P. Nasch and S. Schneeberger, “Annual Report 2006 of Bifacial Thin Industrial Multicrystalline Silicon Solar Cells – BiThink”. Programm Photovoltaik Ausgabe 2007, Forschung. NET Nowak Energie & Technologie AG (Switzerland), pp 75-78, 2007.

[3] G. Bueno, I. Freire, K. Varner, L. Pérez, R. Lago, J.C. Jimeno, J. Salami, H. Kerp, K. Albertsen, A. Shaikh, “Simultaneous Diffusion of Screen Printed Boron and Phosphorus Paste for Bifacial Silicon Solar Cells”. 20th European Photovoltaic Solar Energy Conference and Exhibition. Barcelona, 2005.

[4] H. Kerp, S. Kim, R. Lago, F. Recart, I. Freire, L. Pérez, K. Albertsen, J.C. Jimeno and A. Shaikh. Development of screenprintable contacts for p+ emitters in bifacial solar cells. 21st European Photovoltaic Solar Energy Conference and Exhibition. Dresden, 2006, pp. 892-894.

[5] F. Recart, I. Freire, L. Pérez, R. Lago-Aurrekoetxea, J.C. Jimeno, G. Bueno. Screen printed boron emitters for solar cells. Solar Energy materials and Solar Cells, 91 (2007), pp. 897-902.

[6] I. Hoces, N. Azkona, I. Freire, L. Pérez, R. Lago, F. Recart, J.C. Jimeno, H. Kerp, K. Albertsen and A. Shaikh. “An industrial process for bifacial solar cells based on screen-printing techniques”. This conference.

[7] A. Belyaev, O. Polupan, W. Dallas, S. Ostapenko, D. Hess, J. Wohlgemuth. “Crack Detection and analysis using resonance ultrasonic vibrations in full-size crystalline silicon wafers”. Applied Physics Letters 88, 111907, 2006.

[8] E. Cereceda, J.R. Gutiérrez, J.C. Jimeno, J. Barredo, A. Fraile, E. Alarcón, S. Ostapenko, A. Martínez and M.A. Vázquez. “Crack origin and detection in thin cristallyne solar cells in a production line”. This conference.